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ORDNANCE CORPS · DEPARTMENT OF THE ARMY

REDSTONE ARSENAL

HUNTSVILLE, ALABAMA

TFSO - Memorandum # 15 3 July 1953

Feasibility of a Close Support SSM System
Part I: Design Data

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TFSO Memo # 15 | 28 July 1953

SUBJECT: Feasibility of a Close Support SSM System

PART I: Design Data

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SECTION I - INTRODUCTION

a. General

This office has been requested to submit the results of a feasibility study of a SSM-System to be used in close support of troops, at a level no higher than Army Corps (initiated by letter OCO 471.9/2360 (s), dated 25 June 1952).

Four phases of the study will contribute to the recommendations of the study:

(1) Remarks to the mission of the Army's guided missiles.

(2) Preliminary design of suitable missile configurations.

(3) Survey of applicable guidance systems.

(4) Study of warhead effectiveness for various sizes and types.

The whole subject will be covered by two reports (Parts 1 and 2). This report submits some remarks to the mission of guided missiles and the results of the preliminary design study.

b. Remarks to the Mission of the Army's Guided Missiles.

Guided missiles, in view of their capabilities to carry heavy fragmentation, blast, chemical, bacteriological or atomic warheads provide a logical and essential extension of the Army's traditional artillery arm. It is recognized that, as in any relatively new field, there will be divergent views as to the best utilization of guided missiles. Attempts have been made to pit conventional gun type weapons resp. fighter bombers

against guided missiles in order to establish the superiority of one over the other. This shows clearly a misconception of the application of guided missiles. The interpretation of the result of such attempts at its best is not the published contention that guided missiles come in second best, but that it does not pay just to duplicate the performance of the other weapons by guided missiles. In other words, the governing criteria for a missile weapon should not be conceived as a duplication of effort resulting in eventual replacement of existing weapons but to provide an all-weather fire support beyond the range of heavy guns and the restrictions of fighter bombers. Ordinarily all enemy resources and installations which have a direct bearing on the land campaign are logical and proper targets, their destruction falling within the mission of the Army. Specific types of targets consist not only of attacking or withdrawing forces, troop and vehicle concentration, artillery positions, most of them in close proximity to the front, but also of lines of communications, bridgeheads, supply and maintenance points, headquarters, fortified cities or towns, guided missile launching points and tactical airfields. According to a study conducted by ORO and reported by Memorandum ORO-T-200, August 1952, the bulk of the enumerated targets may be found within a range of 50 miles and only a minority of these targets may also extend beyond the 50 miles up to 150 miles and in very rare cases up to 250 miles. However, these reported

distances from the MLR (mean line of resistance) are subject to be influenced by the development of new weapons and other technological advances. The location of the bulk of the targets just out of artillery range indicates that their usefulness is enhanced by a certain nearness to the front. It can be anticipated that the introduction of a weapon exceeding the range of artillery will change the reported distribution of targets somewhat, but any larger dispersion might affect the enemy front line operations disastrously. The variety of military situations permits in addition to establishing the type of targets to state only generally their probable frequency and density of occurrence, their degree of mobility and an expected but still very flexible distance from the line of friendly troops. This probable frequency will range from numerous to sparse. Targets will be scattered over areas of a few square yards to a square mile and more. A number of targets will be fixed temporarily to only minutes or hours, others days to weeks, or be entirely static. The normal expected distance may reach up to 250 miles. Assessing all these facts serves only to demonstrate that enough lucrative targets exist in this region but that it is impossible to give in advance overiding weights to specific targets at specific ranges. To stop advancing columns at 10 miles distance may be as decisive as to break down the resistance of a fortified city at 50 miles or to destroy at 100 miles supply centers containing large quantities of scarce materials. No one missile could meet

the numerous requirements of these conditions. Therefore, only a family of guided missiles of various ranges and load carrying capabilities, which can be fired from the rear or from the front lines, will insure maximum flexibility and utilization.

The available data fail to provide an adequate statistical answer to decide on the assignment of the number of missiles comprising the Army's family of missiles. So, making the best use of organized knowledge about the subject and considering that in many instances it will be desirable for the Army to locate its guided missile firing points well to the rear for both logistic and security reasons, each of the following ranges is recommended to be covered by an individual missile configuration:

30 N MI: Close Support

75 N MI: Short Range

150-250 N MI: Medium Range

500 N MI and more: Long Range

The objective of this report is to provide data and recommendations for a close support missile and to compare design parameters for short range missiles.

SECTION II - PRELIMINARY DESIGN OF MISSILE CONFIGURATIONS

a. General

A 30 N Mi Close Support Missile or a 75 N Mi Short Range Missile exceeds the range of heavy artillery and is, unlike fighter support,

more independent from adverse weather conditions and covers a high percentage of targets for Army application. The inherent capability of superior ranges and of carrying heavier payloads enables a SSM to cover a larger area in a short time or to knock out a target with less rounds than a gun is able to accomplish. Evaluation of warhead effectiveness versus miss distance will determine the accuracy requirements on the guidance system and by that the number of rounds required to destroy a specific target. However, the actual size of the payload may already be selected by comparing required missile configurations for a variety of payloads and choosing one which has small physical dimensions, provides ruggedness, operational simplicity, reliability, and carries a comparatively high payload. Small dimensions attribute to ease of handling, transportation, mobility, and to camouflaging of position. Safety of friendly troops and low vulnerability suggests single stage missiles (no booster) with supersonic target approach.

For the close support missiles a pressurized liquid propellant system (C-Type) and a solid propellant system were studied for a range of 30 N Mi and payloads of 0 lb, 500 lb, 1000 lb, 1500 lb, and 3000 lb.

For the short range missiles four liquid propellant types and one solid propellant type were investigated for ranges from 30 N Mi up to 75 N Mi and payloads of 1500 lb and 3000 lb. Technical details of these different types will be described in the following paragraphs.

b. Liquid Propellant System

(1) General

The design parameter for the close support and short range liquid propellant missiles have been obtained from results of the so-called optimization study conducted at Redstone Arsenal. The study considered missiles of the ballistic type carrying NE-warheads of 1500 lb, 3000 lb, and 6200 lb over ranges 30 to 250 N Mi. Four basically different missile systems were investigated, each system characterized by a certain type of propellant system, feed system, and certain design features. Those four missile types are called C-Type, H-Type, HG-Type, and HP-Type and are reported in TFSO Memo # 9, 10, 11, and 12.

(2) Principal Data

Principal data characterizing these four missile types are listed in Table 1.

TABLE I

		Missile Type			
		C	H	HG	HP
Feed System		Air-pressurized	Turbopump	Gas-generator & Pressurization	Turbopump
Fuel		Aniline-furfuryl-alcohol	92.5% alcohol	Hydrazine-ammonia	Hydrazine-ammonia
Oxidant		RFNA	LOX	RFNA	RFNA
Specific Impulse	sec	210	235	221	236
Chamber Pressure	psi	300	500	300	500
Mixing Ratio O/F		2.2	1.5	1.5	1.5
Mean Spec. Density of Prop.	lb/ft^3	82.30	60.43	72	72

(3) **Weights and Other Design Parameters**

Design parameters for ranges between 30 and 90 N Mi obtained from the aforementioned reports for the four missile types are listed in Tables II thru V. Thrusts, burning times, and take-off weights as a function of range with the payload as parameter has been plotted in Figures 1, 2, and 3. (It should be noted that slight deviations from the presented thrust values with a corresponding change of the burning times is possible without effecting the presented take-off weight of the various missile types.)

TABLE II

Missile Type		C-TYPE								
Payload	lb	0	500	1000	1500			3000		
Range	NMi	30	30	30	30	60	90	30	60	90
Thrust	lb	3100	5800	8600	12500	16500	21400	24000	32060	39500
Burning Time	sec	66.1	54.76	50.57	50.64	60.5	65	51.3	61.5	65.3
Take-off Wt	lb	1809	3120	4464	6460	8860	11410	12400	17240	21280
Cut-off Wt	lb	833	1607	2393	3445	4108	4789	6537	7851	9002
Diameter	in	21.2	23	24.8	34	34	34	48	48	48
Length	ft	31.1	34.0	36.2	36	41.5	47.5	37.5	37.5	49

TABLE III

Missile Type		H-TYPE					
Payload	lb	1500			3000		
Range	NMi	30	60	90	30	60	90
Thrust	lb	6000	9000	11000	13000	17800	21700
Burning Time	sec	71.5	73.9	75.6	73.5	77.5	79.9
Take-off Wt	lb	4350	5650	6950	8700	10920	12780
Cut-off Wt	lb	2476	2746	3320	4528	4898	5218
Diameter	in	34	34	34	48	48	48
Length	ft	31	33	36	31	34	37

TABLE IV

Missile Type		HO-TYPE					
Payload	lb	1500			3000		
Range	NMi	30	60	90	30	60	90
Thrust	lb	10100	14000	17920	24200	30000	36100
Burning Time	sec	62.3	62.7	63.4	47.5	53.1	57.9
Take-off Wt	lb	5990	7540	9140	11200	13980	16950
Cut-off Wt	lb	3156	3586	4022	6022	6804	7535
Diameter	in	34	34	34	48	48	48
Length	ft	33.2	36.4	39.4	35.8	38.6	42.0

TABLE V

Missile Type		HP-TYPE					
Payload	lb	1500			3000		
Range	NMi	30	60	90	30	60	90
Thrust	lb	8000	11000	13300	14500	18500	22200
Burning Time	sec	67	66.8	66.9	69.0	73.5	75.2
Take-off Wt	lb	4830	5910	6750	8890	10780	12430
Cut-off Wt	lb	2510	2732	2901	4562	4901	5213
Diameter	in	34	34	34	48	48	48
Length	ft	29.1	31.4	33.1	30.9	33.0	34.5

c. Solid Propellant System

(1) General

Several features of solid propellants may contribute to more favorable configurations of the close support and short-range missiles. Out of a number of possible choices, the solid propellant T-17, as developed by the Thiokol Corporation, has been selected for this application, because of its well established performance characteristics for high thrust and long duration units.

The selection of solid propellant thrust units for the missile study was based on the following consideration. It would be desirable to have neither a progressive nor a retrogressive characteristic of the thrust over the duration and to have practically no sliver-loss of the propellants. These requirements depend largely on ballistic properties and grain

configurations and are not all consistent with each other. One grain configuration, which would meet constant burning surface and small sliver-loss, is the rod and tube design which, although possible, is difficult in its application because of the necessary rod support. Another design, theoretically rendering constant burning surfaces and low sliver-loss, is the hollow cylinder with tapered ends. Besides its disadvantage of giving a greater length, its applicability has not been proven satisfactorily for large units in actual tests as yet. Therefore, the conventional n-pointed star was adopted for all further investigations. However, this type of construction allows very little freedom to control the form of the thrust-time function and a progressive thrust characteristic will ordinarily result.

To expedite the study a five pointed star configuration has been selected. This configuration counteracts the tendency of the hemispherical head and of the star perforation to increase their perimeter during the burning time by appropriate tapering of the end of the grain. The correct taper will follow a flat curve, which, for practical reasons, will be approximated by a conical shape.

(2) Principal Data

Operational data, ballistic and physical properties used in this study are as follows:

Chamber pressure	P_c = 600 psi
Specific impulse, motor	I_o = 187 and 200 sec
Specific impulse, missile	I_m = 181.4 and 194 sec
Burning rate	r = .233 in/sec
Specific weight of propellant	p = 1.63 kg/ltr = .0589 lb/in^3
Ratio burning-surface/Port area	$G = \frac{A_B}{A_P} = 122$
Ratio Port area/Throat area	$\frac{A_P}{A_T} = 2.7$
Ratio burning-surface/Throat area	$K = \frac{A_B}{A_T} = 330$

(3) Weights and other design parameters

The weights of the various missile components have been estimated by employing semi-emphirical formulas and similarity considerations with existing designs. A method, establishing a minimum required motor diameter and lowest casing weight for a given total impulse, is outlined in detail in appendix 1 and 2. A breakdown of components according to their dependency on total impulse, thrust, payload, and diameter yielded the following relation for the "hardware weight" W_e of the investigated configurations:

$$W_e = C + F(at + b)$$

with F = Average thrust (const.)

t = Corresponding burning time

Values for C, a, and b are listed in Table VI considering conservative motor weights:

TABLE VI

Payload Configuration	C	a	b
0	390	.002070	.0039
500	890	.002068	.0039
1000	1390	.002066	.0039
1500	1890	.002064	.0039
3000	3390	.002058	.0039

Based on the aforementioned weight equations, a number of configurations have been established for the various payloads and their ballistic ranges were calculated for a specific impulse I = 187. Aerodynamic coefficients used for the performance calculations are reported in TFSO Memo # 21. Design parameter and resulting ranges are listed in Tables VII and VIII.

TABLE VII

Payload	Thrust	Duration	Tot. Impulse	Take-off weight	Burn-out weight	Diameter Motor	Diameter Missile	Ballistic Range-NMI
0	10975	11.94	131,040	1406	705	16.94	17.0	22.5
	11816	12.39	146,400	1525	740	17.58	18.0	24.7
	12869	12.93	166,400	1675	785	18.34	18.5	28.6
	13938	13.46	187,600	1833	833	19.09	19.5	33.5
500	15989	14.41	230,400	2660	1428	20.44	20.5	24.6
	17442	15.05	262,500	2905	1501	21.35	21.5	28.6
	18352	15.44	283,360	3063	1546	21.90	22.0	34.17

TABLE VIII

Payload	Thrust	Duration	Tot Impulse	Take-off weight	Burn-out weight	Diameter motor	missile	Ballistic Range-NMi
1000	21908	16.87	369,600	4216	2240	23.93	24.0	24.5
	23946	17.64	422,400	4616	2357	25.05	25.5	32.5
	24596	17.87	439,530	4742	2391	25.35	25.5	33
1500	27734	18.98	526,400	5900	3085	26.93	30.0	23.4
	29680	19.63	582,610	6317	3202	27.85	30.0	28
	30490	19.90	606,750	6507	3265	28.23	30.0	30.5
	37141	21.96	815,625	8087	3714	31.15	31.5	52.5
	50495	25.61	1,293,200	11668	4749	36.33	37.0	78.3
	63000	28.61	1,802,450	15491	5848	40.59	41.0	96.5
[illegible]0	41329	23.17	957,600	10646	5525	32.87	48.0	22.10
	43761	23.85	1,043,700	11280	5699	33.84	48.0	30.0
	54845	26.70	1,464,375	14446	6612	37.88	48.0	50.81
	73854	30.98	2,288,000	20619	8378	43.95	48.0	85.15
	91714	34.52	3,166,000	27196	10255	48.97	49.0	109.7

Take-off weights vs Ballistic Range is plotted in Figure 4.

(4) Modification of Missile Configuration

Since no actual flight experience exists of solid propellant missiles of these sizes, the aforementioned ranges were obtained for rather conservative missile weights. It is felt, however, that especially the motor weights can be reduced after results of a more extensive study of the external loads on the motor is available. Furthermore, tests already conducted demonstrated achievable specific impulses of 200 sec and higher for solid propellant types TRX 110A and TRX 121. A higher specific impulse and a higher allowable stress will decrease the weight of the motor, which will in turn result in more favorable missile

configurations. In order to estimate this influence on the design parameters, it has been assumed that the total impulse required to transport 1 lb of hardware will remain constant for a specified range. This assumption will serve only to establish the order of magnitude of the change in the design parameters and has been applied for the 1500 and 3000 payload configurations.

The relation $\frac{F \cdot t}{W_e} = K$ has been evaluated from the actual calculated configurations and the values of K are listed in Table IX.

TABLE IX

Payload	Range	K
1500	30.5	186
1500	52.5	220
1500	78.3	272
1500	96.5	308
3000	30.0	183
3000	50.81	221
3000	85.15	273
3000	109.7	309

Using now the weight equation

$$W_e = C + F(at + b)$$

with the constants:

$C = 1890$
$a = .001714$ for 1500 payload
$b = .0039$

$C = 3390$
$a = .001708$ for 3000 payload
$b = .0039$

permits to calculate $K = \frac{Ft}{W_e} = f(F.t)$ and to read off from graphs presenting $K = f(F.t)$ the required total impulse for the established K - values.

Knowing the total impulse allows to calculate for $I = 200$ sec and for an allowable stress of the motor casing of $\sigma = 65{,}000$ psi (see last equation in Appendix 1):

$$t = \frac{F.t}{82.52}$$

$$F = \frac{F.t}{t}$$

$$W_e = C + F(at + b)$$

$$W_p = \frac{Ft}{200}$$

$$W_o = W_e + W_p$$

The resulting weights for 1500 and 3000 lb payloads and ranges between 30 and 100 N Mi are also plotted in Figure 4.

SECTION III - TYPE OF TRAJECTORY

The majority of S-S-guided missiles existing or under development perform ballistic trajectories. All these missiles operate with a liquid propulsion system which provides readily the means of a controlled power cut-off. Relying on an accurate power cut-off, various methods for the guidance systems were devised, which result in certain impact accuracies depending mainly on the accuracy in controlling missile position and

velocity vector at cut-off. Any of these methods may be applied also to liquid propellant close support missiles. This is different for the solid propellant missiles, since no practical means of obtaining a power cut-off has been demonstrated as yet.

The General Electric Company suggests in their proposal of a solid propellant missile a so-called "constant slant range" trajectory which takes the missile out of an initially ballistic trajectory with a steep turn into a constant slant range. It is apparent that this shaping of the trajectory requiring continuous control eliminates the need of having a power cut off, but it also reduces the range as compared with a ballistic trajectory. Consequently, in comparing a liquid propellant missile with a solid propellant missile guided along a constant slant range, one has to compare the design parameter for a ballistic range with the ones for a constant slant range. A typical constant slant range trajectory is shown in Figure 5. In order to estimate the reduction in range, a number of solid propellant configurations have been calculated maneuvering a steep turn with approximately 5 g. The resulting constant slant ranges are plotted versus ballistic ranges in Figure 6.

SECTION IV - COMPARISON OF CONFIGURATIONS

The resulting missile configurations for 30 N Mi from the comparative study for solid and liquid propellants (C-type missiles) are shown in Figure 7. Their take off weight versus payload is shown in Figure 8.

Figures 9 and 10 present for the 1500 lb payload and the 3000 lb payload the take-off weight as function of range for the two solid missiles (F_{sp} = 187 sec, σ = 46,000 psi and F_{sp} = 200; σ = 65,000 psi) and the four liquid missile systems studied. From these two figures it can be seen that the lowest take-off weights will be achieved with liquid propellants of pump feeding type. Solid propellant missiles and liquid propellant missiles of air-pressurization and gas-generator type are very close together in their take off weight requirements. This and the fact of having smaller dimensions and greater simplicity favors definitely for close support application of solid propellant missiles over liquid propellant missiles of air-pressurization and gas-generator types. It leaves then for the final selection of the best suitable propulsion system for the close support missile type to compare and weigh simplicity and compactness of solid propellant missiles against the somewhat larger and more complex pump type missiles of lower take-off weights.

The following enumeration of unfavorable and favorable features of the solid propellant missiles compared to the liquid pump type missiles will assist in this selection:

a. Unfavorable features of solid propellant missiles:

(1) No means of thrust cut off (at least at the present time). This increases considerably the difficulty in the choice of an accurate guidance system. Choosing a radio system requires radar control all the way and any chosen system requires a special trajectory shaping which needs a higher mechanical and control power, leading to a heavier missile than needed for a purely ballistic trajectory.

(2) A slightly lower specific impulse than most liquid propellants.

(3) High take-off acceleration and short burning times may bring complications to ground equipment and flight control.

(4) High cost of propellants at present production status.

(5) Heavy motor casing structure by high pressure application.

b. Favorable Features of Solid Propellant Missiles

(1) Density of propellants higher than any liquid propellants in use.

(2) No propellant feeding system, thus eliminating the need for pumps, turbines, generators, pressure bottles, heat exchanger, control valves, main valves, pipe systems, and auxiliary electrical equipment.

(3) No injection system.

(4) No cooling system for combustion chamber, thus eliminating double walls or tubular channel arrangement.

(5) Combustion chamber and propellant containers are an integral unit, resulting in shorter missiles and reduced heights of superstructures of test-stands.

(6) No filling system required within the missile, thus eliminating the need for valves and pipes aboard and for valves, pipes, metering equipment and servicing vehicles on the ground.

(7) No propellant storage and supply facilities required.

(8) Reduced time for launching preparations by not having to fill the containers, to replenish vaporized liquids and to check the propellant feeding system.

(9) No materials required able to withstand aggressive propellants or brittling effects of very low propellant temperatures.

(10) Higher reliability, since number of components is essentially smaller than in a pump feeding liquid propellant system.

SECTION V - SUMMARY AND CONCLUSION

Based on findings of an ORO - Target Evaluation Study, the range of a close support missile has been specified to 30 N Mi. Concluding from the referred target evaluation study, it can be stated that more than 50% of all targets of immediate interest to AFF can be found within 20 to 30 N Mi behind the MLR with a small number of possible targets tapering out to approximately 250 N Mi. Targets within 30 N Mi are partly out of the range of heavy artillery and may also be too numerous to justify employment of short or medium range missiles against them. For these reasons it is believed that a close support missile covering a maximum range of 30 N Mi will close an existing gap in the Army weapon system and bring a high percentage of tactical area of immediate interest under control of this new weapon.

The tactical employment of a close support missile calls for launching sites close to the front lines for which ruggedness, simplicity, fastest preparation times, least ground equipment, and smallest possible dimensions are of paramount interest. Inspecting the results of the comparison study

as shown in Figures 7, 8, 9, and 10 and stated in section IV show that liquid propellant pump type missiles are not competitive in meeting the aforementioned criteria. They are of a small take-off weight, a favorable characteristic which in itself is not of sufficient importance to compensate for the other less favorable features. The solid propellant missile comes closest in representing all these desirable features and will constitute the best solution for a close support missile from a design and production as well as operational point of view.

The recommended missile is, therefore, a solid propellant type missile. Comparing the missile dimensions in relation to their respective useful payloads leads to the conclusion that up to 1500 lb payload the missile dimensions differ only slightly. The dimensions are strikingly different for 3000 lb payload. It appears that the selection of 1500 lb payload is the best combination of smallest missile and heaviest payloads for which HE or NE-warheads could be used alternately. It can be anticipated that the introduction of a close support missile will force some targets out of this specific range. In order to meet this resulting condition, it is suggested to add to the close support missile a short range missile. The same considerations as applied to the close support missile lead also to the selection of a solid propulsion system for the short range missile.

As mentioned in section II, paragraph c (4), there is sufficient evidence to believe that higher solid propellant performance may be expected to be utilized in a near future development. Assuming this progress in

propellant development and the concept of a close support missile and a short range missile, two missile configurations based on a nominal range of 30 N Mi and 75 N Mi and 1500 lb payload have been sketched in Figure 11.

SECTION VI - RECOMMENDATION

It is recommended to establish the concept of controlling a zone of approximately 60 N Mi from the front line into enemy territory by a close support and a short range missile. Both missiles are to be based on a solid propellant basis, on a nominal range of 30 to 75 N Mi, and on 1500 lb payloads HE and NE. The design will endeavor to retain nose and tail section for both missile types and make the components adaptable to either motor required.

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APPENDIX I

Determination of the motor diameter

In order to establish the relations between motor dimensions, thrust and duration, for a preliminary study of a family of missiles, the following method has been applied for grain configurations based on geometrical relations as shown in Figure 12:

The Port Area is determined by its geometrical dimensions to

$$A_p = 5\left[\frac{R_1 r}{2} + 2R_1(x - R_1 \operatorname{ctg}\alpha) + R_1^2 \operatorname{ctg}\alpha\right] \tag{1}$$

substituting $\alpha = 36^\circ$ for a 5-pointed star, yields

$$x = \frac{A_p}{10 R_1} - 0.0968 R_1 \tag{2}$$

The initial burning-surface is in good approximation

$$A_B \doteq L_1\left[5 R_1 \pi + 10(x - R_1 \operatorname{ctg}\alpha)\right] + 2(x + R_1)^2 \pi \tag{3}$$

Taking a slenderness ratio of the port

$$\frac{L_1}{2(x + R_1)} = 7 \tag{4}$$

as used for the A-2 motor, and a ratio

$$\frac{A_B}{A_p} = 122 \tag{5}$$

results in

$$122\, A_p = 14(x + R_1)\left[5 R_1 \pi + 10(x - R_1 \operatorname{ctg}\alpha)\right] + 2(x + R_1)^2 \pi$$

$$x = \pm \sqrt{0.834\, A_p + 0.15\, R_1^2} - 0.6125\, R_1 = \frac{A_p}{10\, R_1} - 0.0968 \qquad (6)$$

or $$R_1 = 0.117 \sqrt{A_p} \qquad (7)$$

According to Figure 12, the diameter of the motor is

$$D_M = 2\, R_M = 2\,(x + R_1 + rt)$$

$$D_M = 2\left(\frac{A_p}{10\, R_1} + 0.9032\, R_1 + rt \right) \qquad (8)$$

Since the thrust and burning times are dependent on the pressure sensitive burning rate and surface, a minimum satisfactory value of the flow channel area A_p is usually and successfully specified in terms of the burning-surface A_B by a limiting value of the ratio

$$G = \frac{A_B}{A_p} \qquad (9)$$

The use of this restriction, the selected charge shape and the aforementioned ballistic properties, determine the required charge mass and by that the dimensions for a motor of specified performance data by substituting

$$\frac{A_B}{A_p} = 122 \quad \text{and} \quad A_B = \frac{F}{r \cdot \gamma_p \cdot I_e}$$

in equation (8) which yields

$$D_M = 0.466t + 0.1086 \sqrt{F} \;;\; \text{for } I = 187 \text{ sec} \qquad (10)$$

$$D_M = 0.466t + 0.1050 \sqrt{F} \;;\; \text{for } I = 200 \text{ sec} \qquad (11)$$

where t = duration (sec)

F = thrust (lb)

D_M = diameter of motor (in)

Any given total impulse can be obtained with various combinations of F and t, but only one combination renders the smallest motor diameter for a specified total impulse as shown in Figure 13 for total impulses up to 2,000,000 lb/sec. Evaluation of Figure 13 (obtained from equations 10 and 11) also yields the relation between D_M min and duration t with

$$D_{M_{Min}} = 1.4187\ t \tag{12}$$

which is apparently independent from the specific impulse.

Substituting the $D_{M_{Min}}$ for D_M in the general equation of the motor diameter (equations 10 or 11) renders the relation between thrust and burning time dependent on the specific impulse for $D_{M_{Min}}$ - configurations.

$$D_{M_{Min}} = 1.4187\ t = .466\ t + a\sqrt{F} \tag{13}$$

where $a = .1086$ for $I = 187$ sec

$a = .1050$ for $I = 200$ sec

or for $I = 187$ sec:

$$F = 76.97\ t^2 \tag{14}$$

and for $I = 200$ sec

$$F = 82.82\ t^2 \tag{15}$$

F and F.t vs t for $D_M = D_{M_{Min}}$ is plotted in Figure 14.

APPENDIX 2

Weight of Motor Casing

The chamber weight was obtained from the formula for the weight of a thin-walled pressure vessel consisting of a cylinder with hemispherical ends:

$$W_c = \gamma \cdot \delta_c \left[\pi D L_c + \frac{\pi D^2}{2} \left(\frac{\delta_f}{\delta_c} + \frac{\delta_a}{\delta_c} \right) \right] \tag{16}$$

where $\frac{\delta_f}{\delta_c}$ = ratio of forward-head gage to cylinder-wall gage = .8

$\frac{\delta_a}{\delta_c}$ = ratio of aft-head gage to cylinder-wall gage = 1.6

γ = material density = .283 (lb/in^3)

δ_c = cylinder-wall gage (in)

D = diameter of casing (in)

L_c = length of cylinder (in)

Using now a ratio

$$\lambda = \frac{L_c}{D} = 4 \quad \text{and} \quad \delta_c = \frac{p \cdot D}{2\sigma}$$

where p = average chamber pressure = 600 (psi)

σ = allowable stress considering external loads (psi)

The above weight equation may then be written:

$$W_c = 1386 \frac{D^3}{\sigma} \quad \text{(lb)} \tag{17}$$

It was assumed that the propellant would be bonded to the inner surface of the chamber by a 1/16 inch, rubber-base liner of density

$$\gamma_L = 0.05 \text{ lb/in}^3$$

The weight of this component is therefore given by

$$W_L = 0.049\ D^2 \qquad (18)$$

The nozzle weight was computed by the following formula, which was derived on the bases of the "Sergeant" nozzle design: (JPL Progress Report No. 4-118)

$$W_N = A_p\,(2.41 + 13.73 \cdot 10^{-6} \cdot p_c \cdot \sqrt{A_p})$$

$$\text{where } A_p = \text{Port Area} = \frac{F}{r \cdot \gamma_p \cdot I \cdot 122} = .00319\ F$$

$$\text{or } W_N = F\,(0.00768 + 0.0000144\ \sqrt{F})$$

A numerical evaluation resulted in the following approximations

$$W_N = 0.00814\ F \qquad (19)$$

It has been assumed that a sliver loss of 2% of the total amount of propellant will be attainable.

$$W_{SL} = 0.02\ \frac{F \cdot t}{I} = .000107\ Ft \qquad (20)$$

The total weight of the motor including sliver-loss results then to:

$$W_M = W_c + W_L + W_N + W_{SL} = \frac{13.6}{\sigma} D^3 + 0.00814F + 0.049D^2 + 0.000107F$$

$$W_M = D^2\left(\frac{1386}{\sigma} D \cdot 0.049\right) + F(0.00814 + 0.000107t) \qquad (21)$$

The above equation for the weight of the motor indicates that the lowest weight will be achieved at the smallest required diameter of the motor. This justifies the use of the thrust-duration relation pertaining to $D_{t_{Min}}$. Two motor weights as a function of total impulse have been calculated, one for a conservative assumption of σ and the other for a higher but still allowable stress (approximately σ = 45,000 and 65,000 psi). The weights are plotted in Figure 15.

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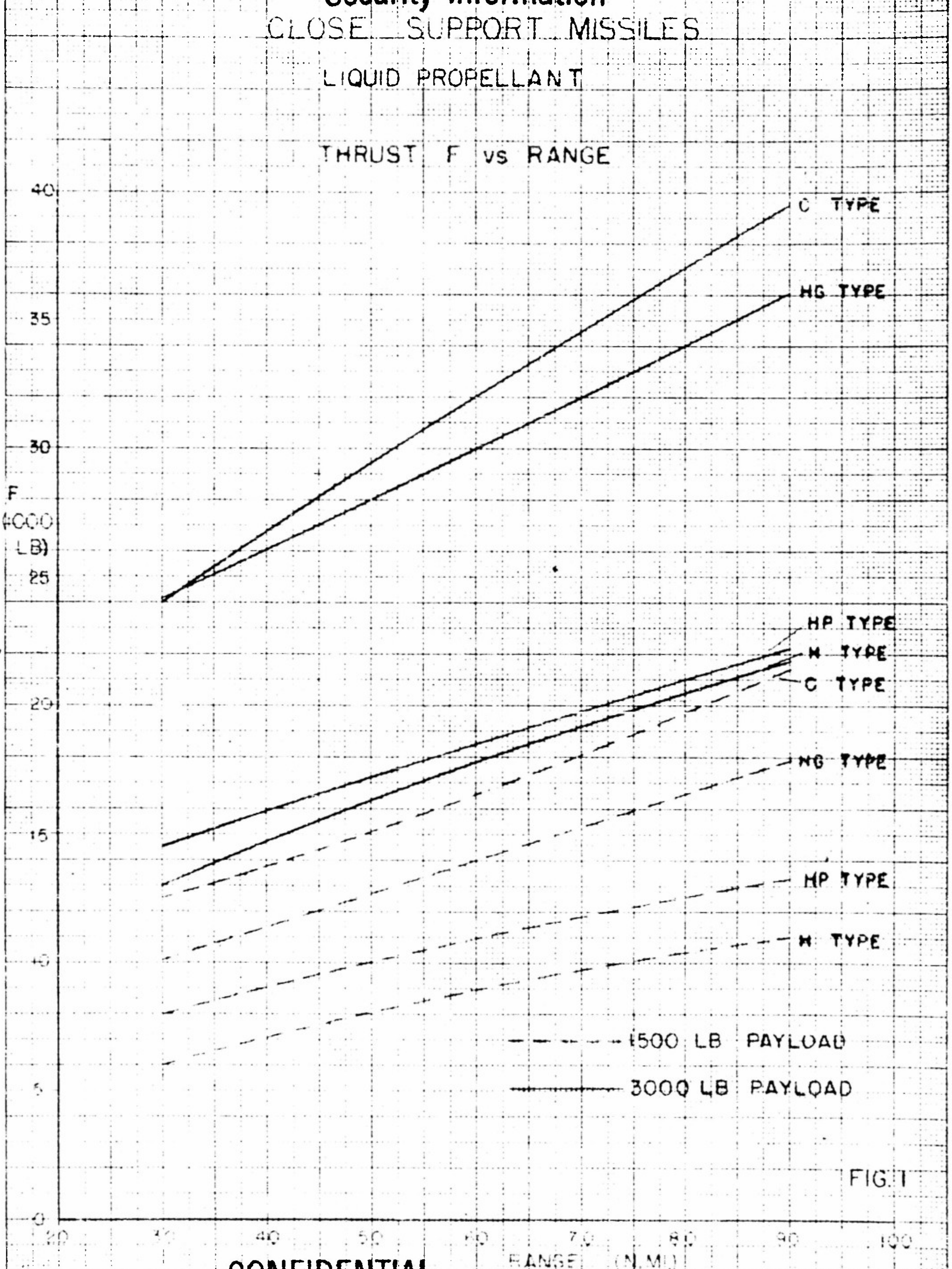

FIG. 1

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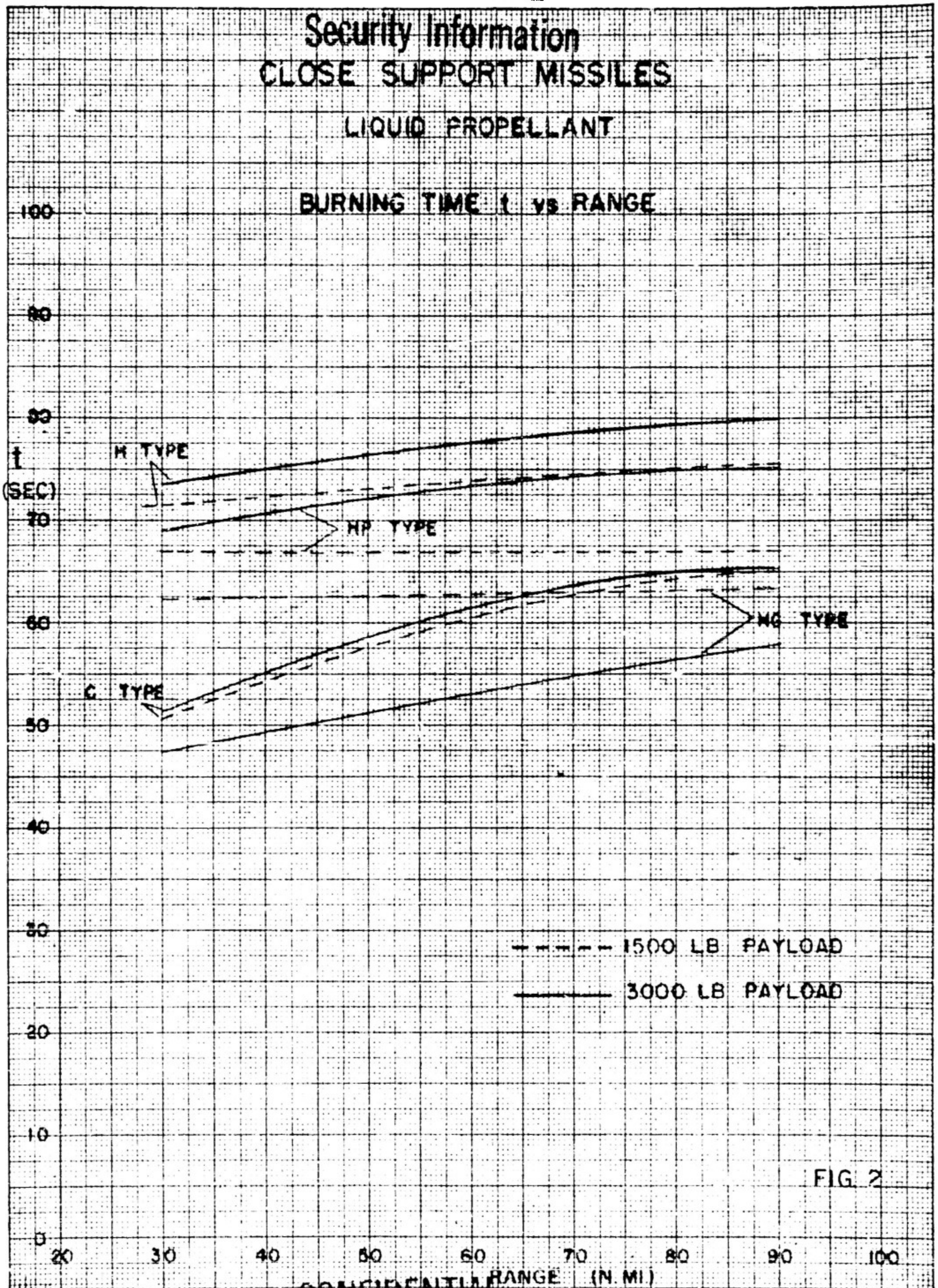

FIG. 2

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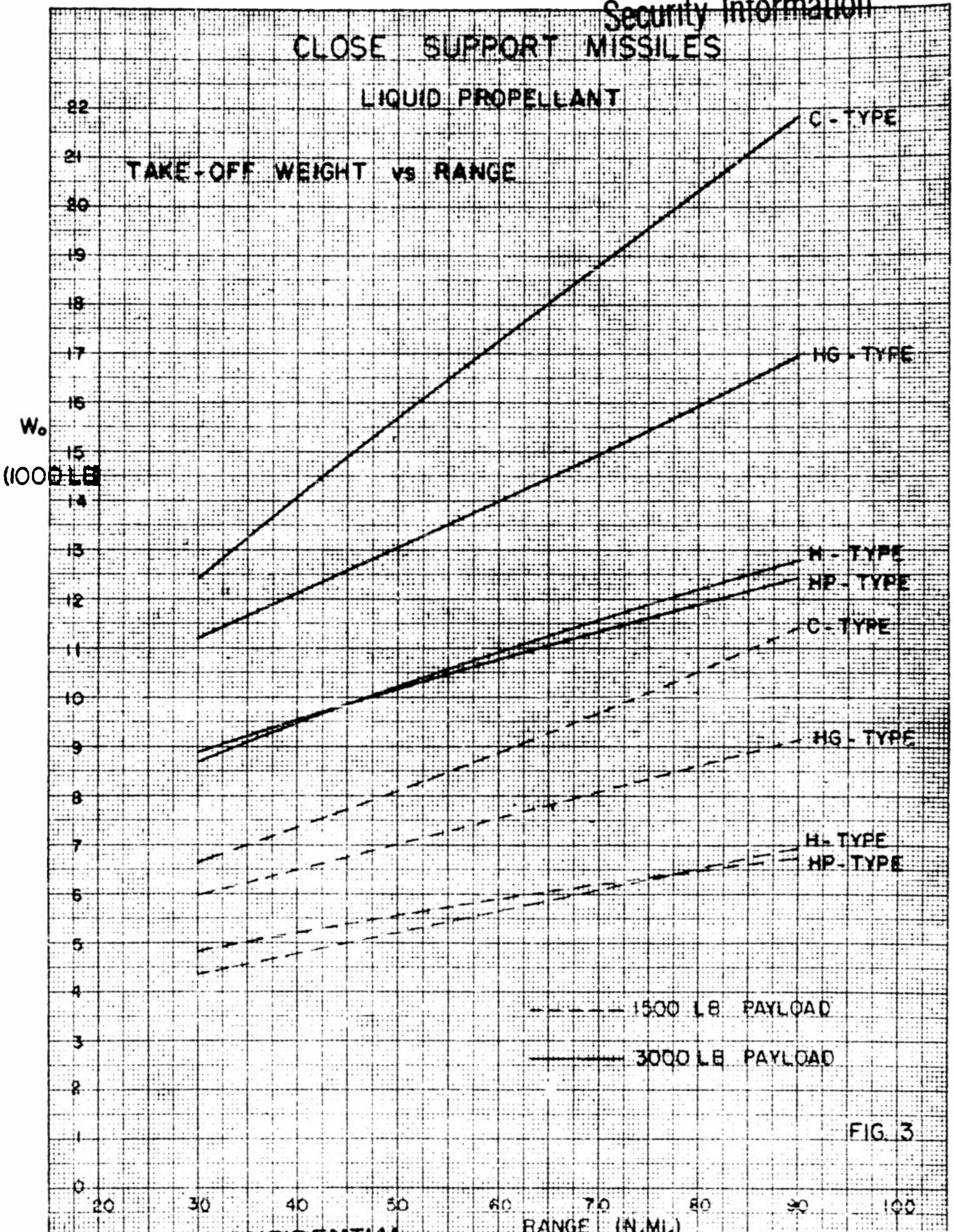

FIG. 3

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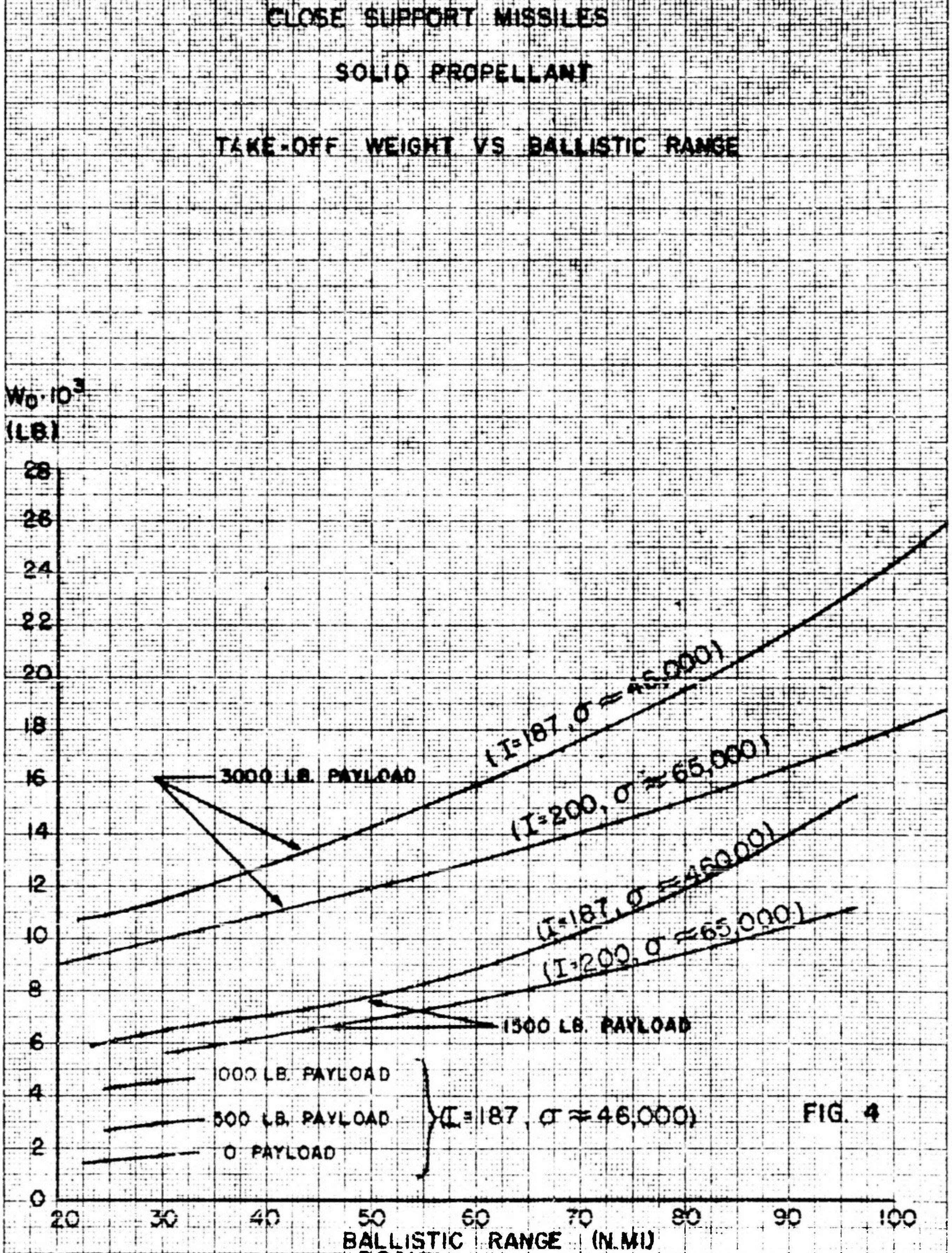

FIG. 4

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CLOSE SUPPORT MISSILE

ALTITUDE VS RANGE

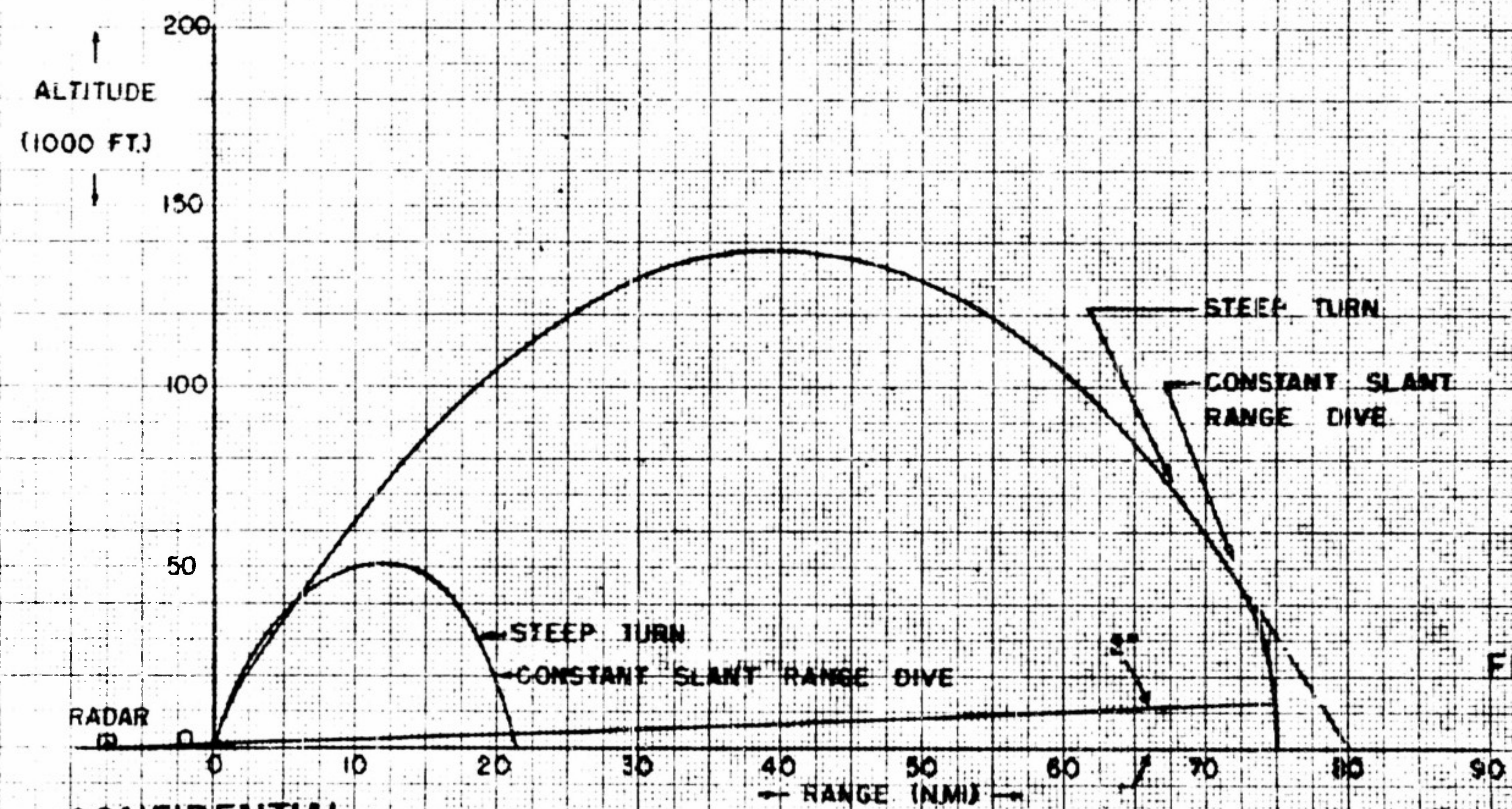

FIG 5

TYPICAL CONSTANT SLANT RANGE TRAJECTORIES

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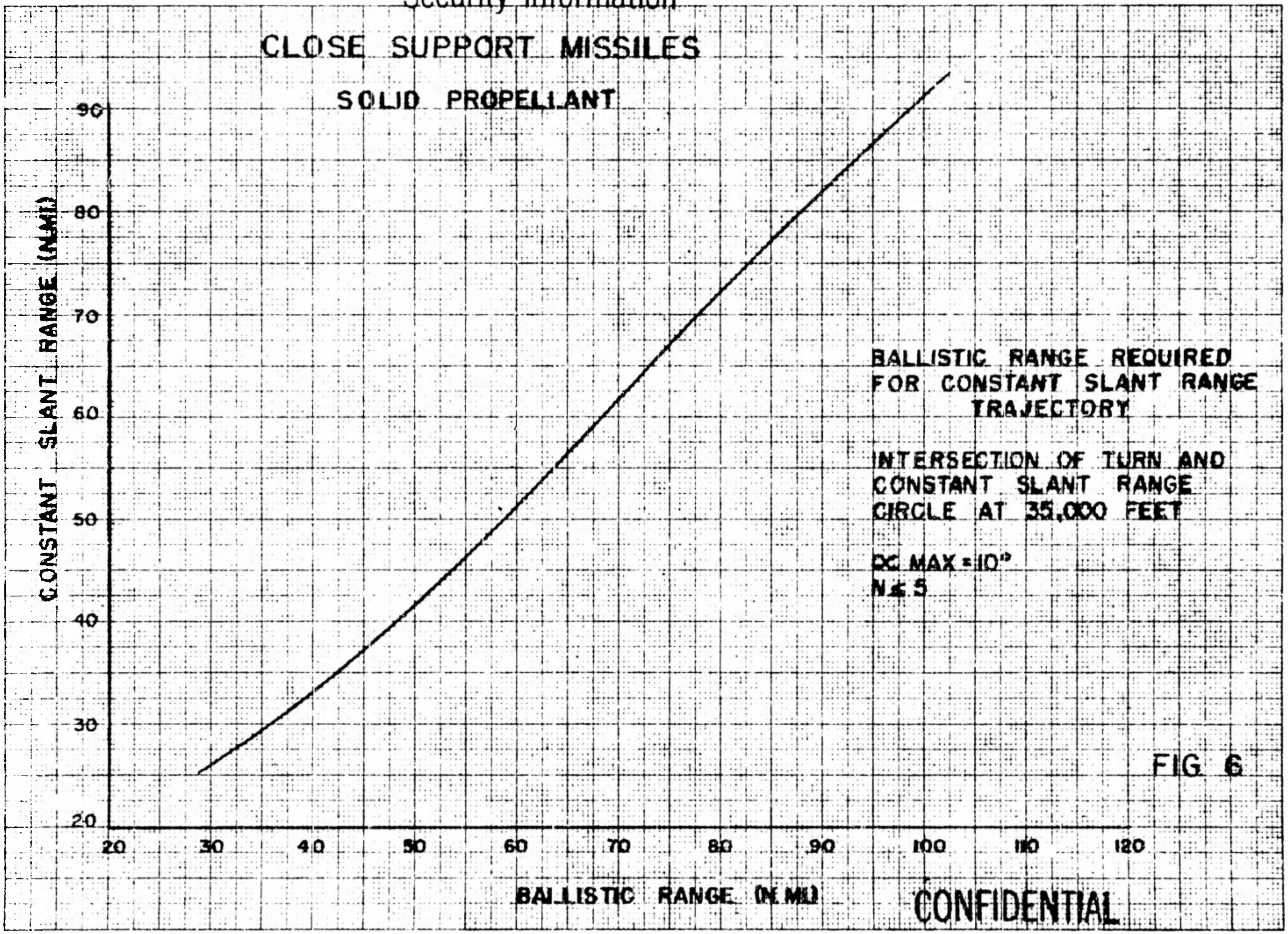

FIG 6

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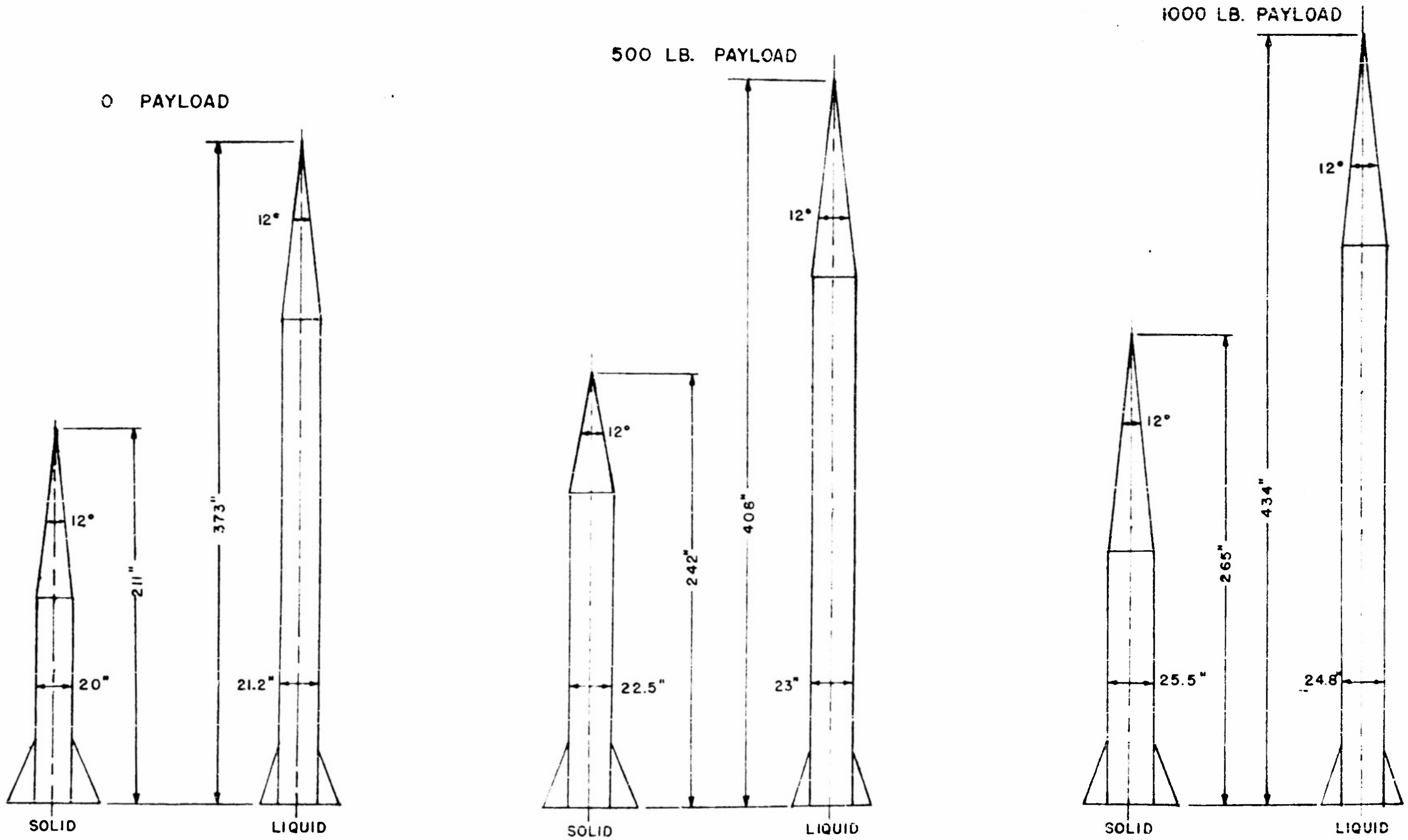
CLOSE SUPPORT M

RANGE 30 N.MI.



	0 PAYLOAD SOLID	0 PAYLOAD LIQUID	500 LB. SOLID	500 LB. LIQUID	1000 LB. SOLID	1000 LB. LIQUID
THRUST (LB)	14,300	3,100	19,000	5,800	25,000	8,600
DURATION (SEC)	14	66.1	16	54.8	18	50.6
TOTAL PROPELLANT WT. (LB)	1,047	976	1,600	1,513	2,370	2,071
TOTAL DRY WT (LB)	853	833	1,600	1,607	2,430	2,393
TOTAL TAKE-OFF WT (LB)	1,900	1,809	3,200	3,120	4,800	4,464

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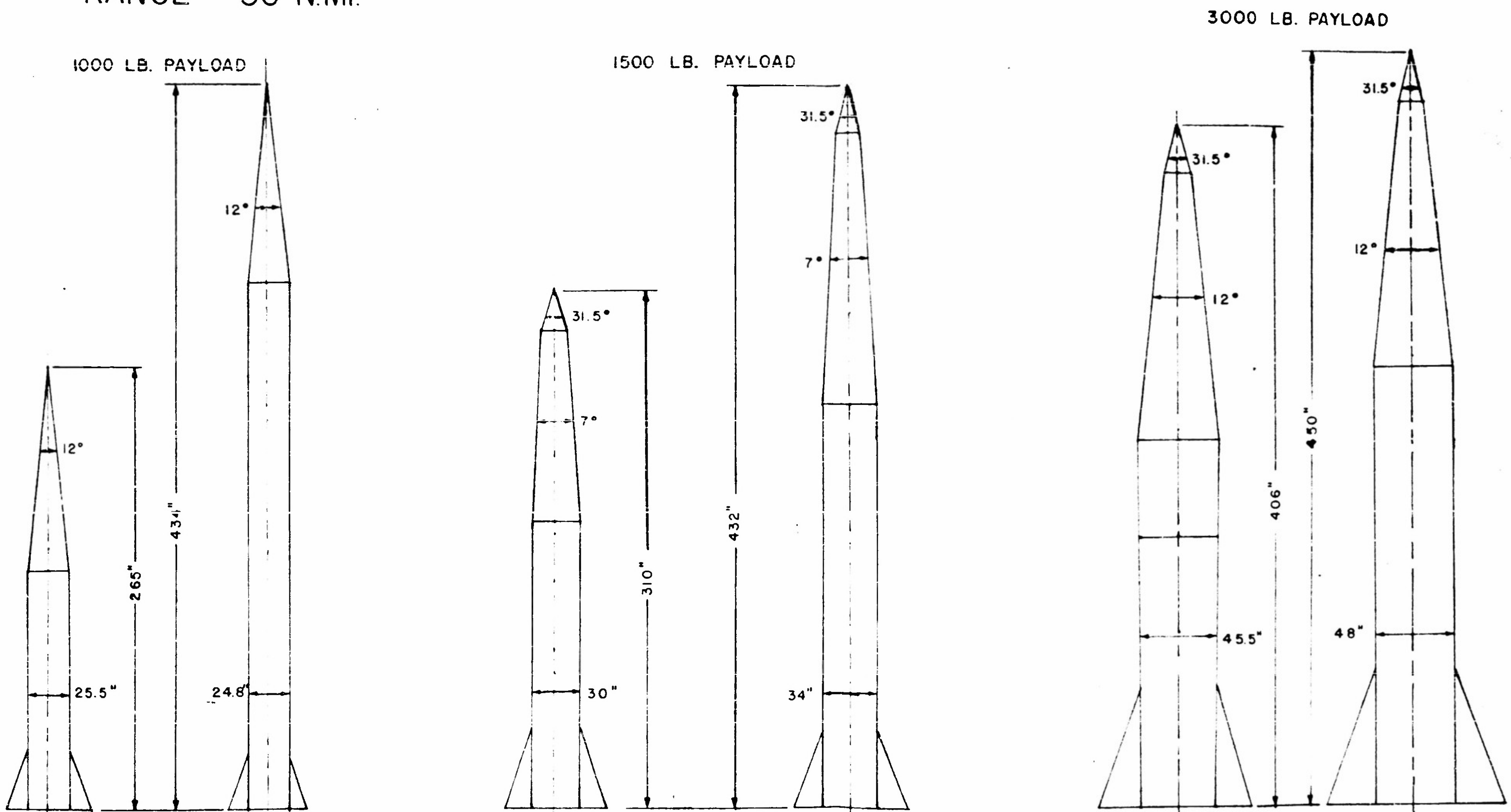
CLOSE SUPPORT MISSILES

FIG. 7

RANGE 30 N.MI.



SOLID	LIQUID	SOLID	LIQUID	SOLID	LIQUID
25,000	8,600	32,000	12,500	45,500	24,000
18	50.6	20	50.6	24.5	51.3
2,370	2,071	3,428	3,015	5,894	5,863
2,430	2,393	3,372	3,445	6,306	6,537
4,800	4,464	6,800	6,460	12,200	12,400

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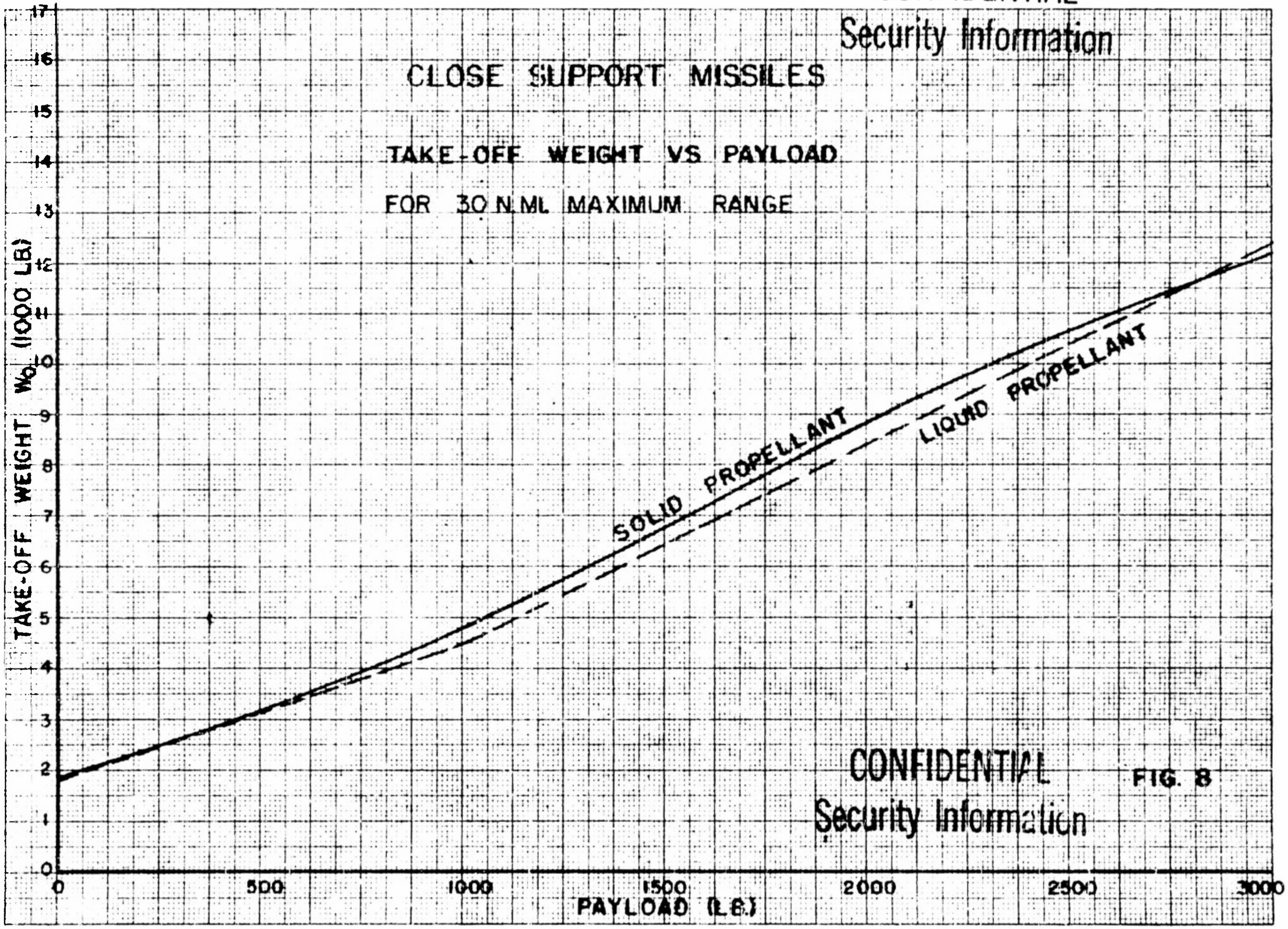

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FIG. 8

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CLOSE SUPPORT MISSILE

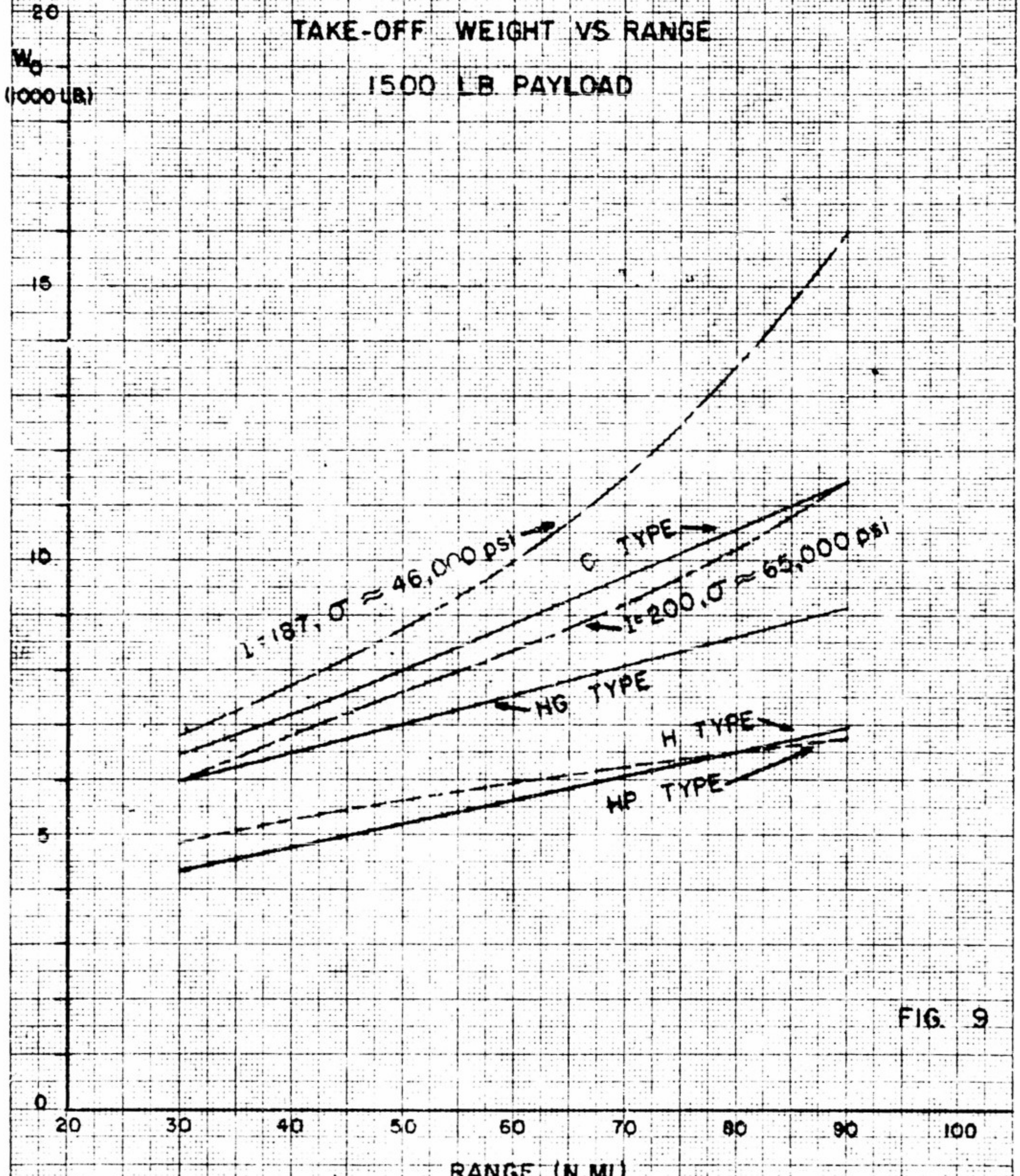

FIG. 9

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CLOSE SUPPORT MISSILE

TAKE-OFF WEIGHT VS RANGE

3,000 LB PAYLOAD

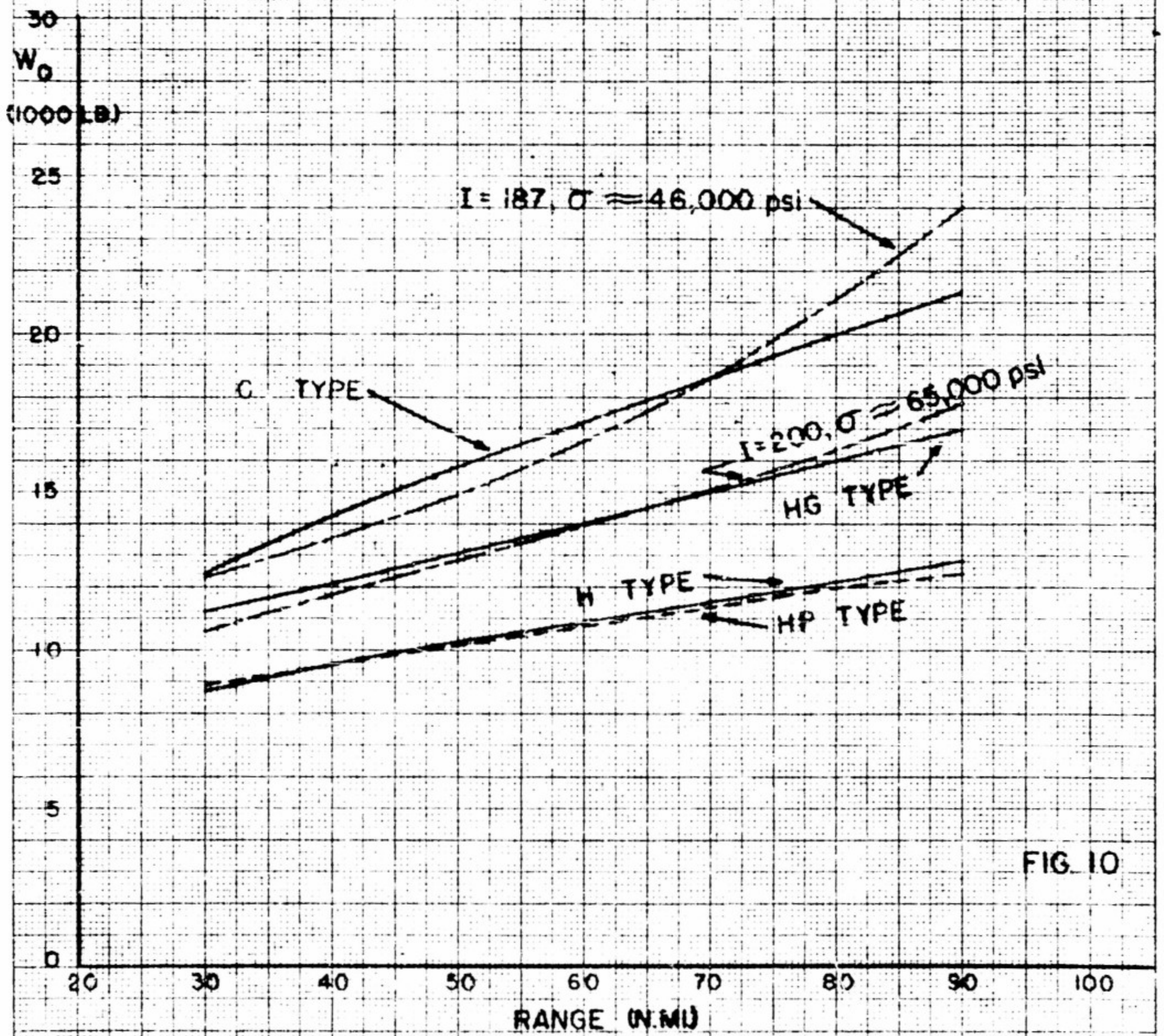

FIG. 10

SOLID PROPELLANT MISSILES

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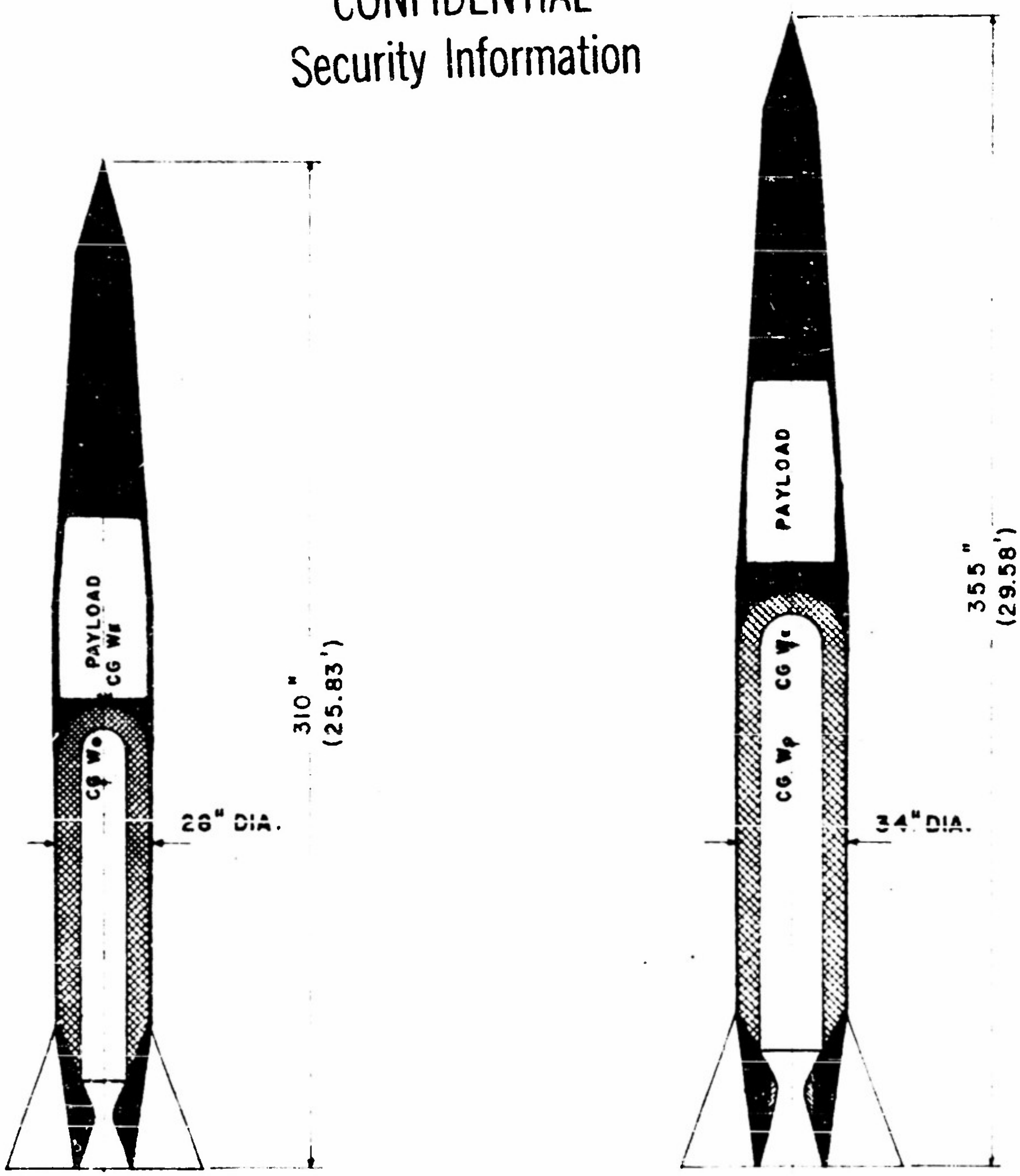

30 NMI	RANGE	75 NMI
1500 LB	PAYLOAD	1500 LB
31000 LB	THRUST	47500 LB
19 SEC	DURATION	24 SEC
6010 LB	TAKE-OFF WEIGHT	9713 LB
3033 LB	CUT-OFF WEIGHT	4024 LB

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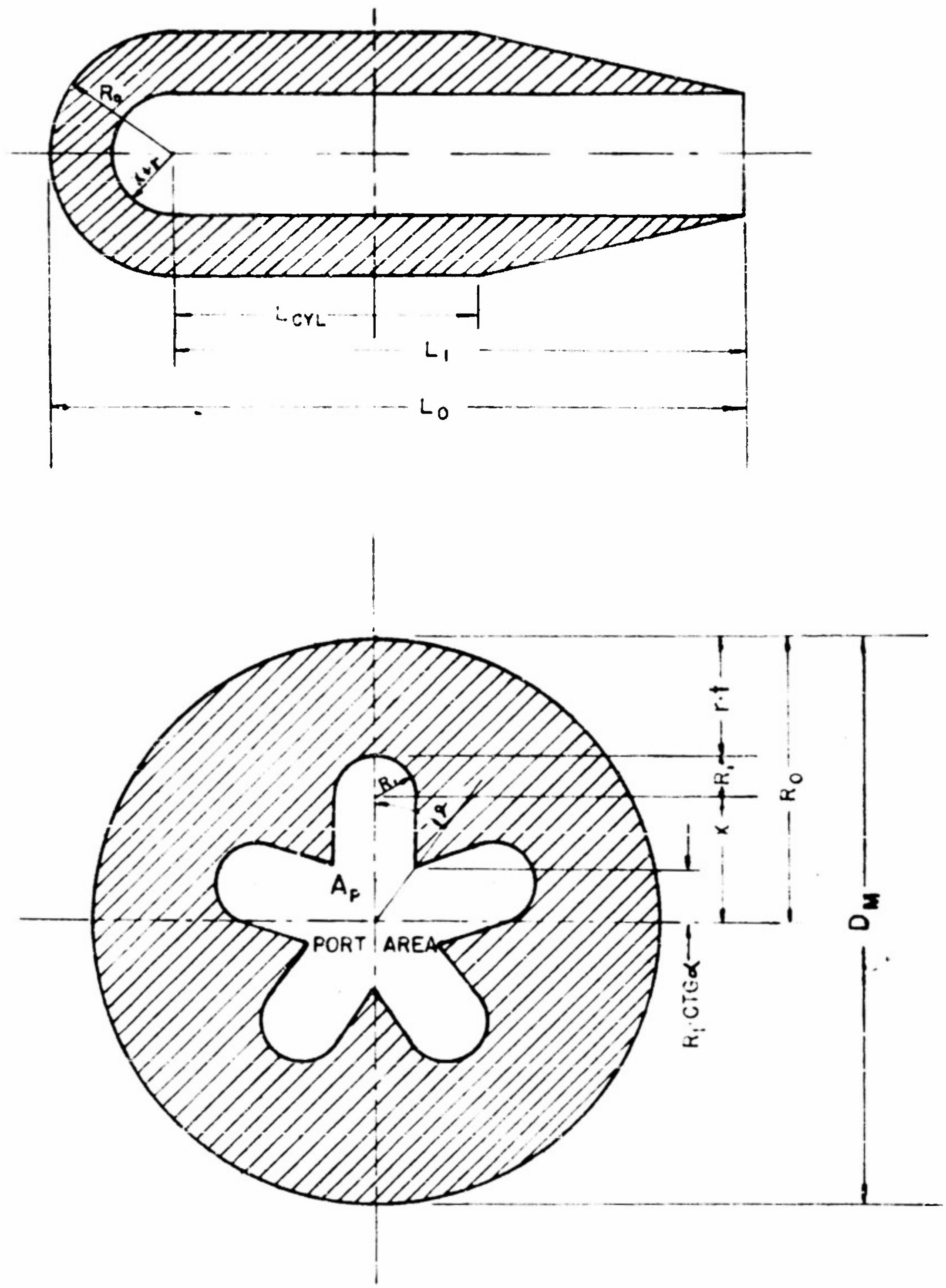
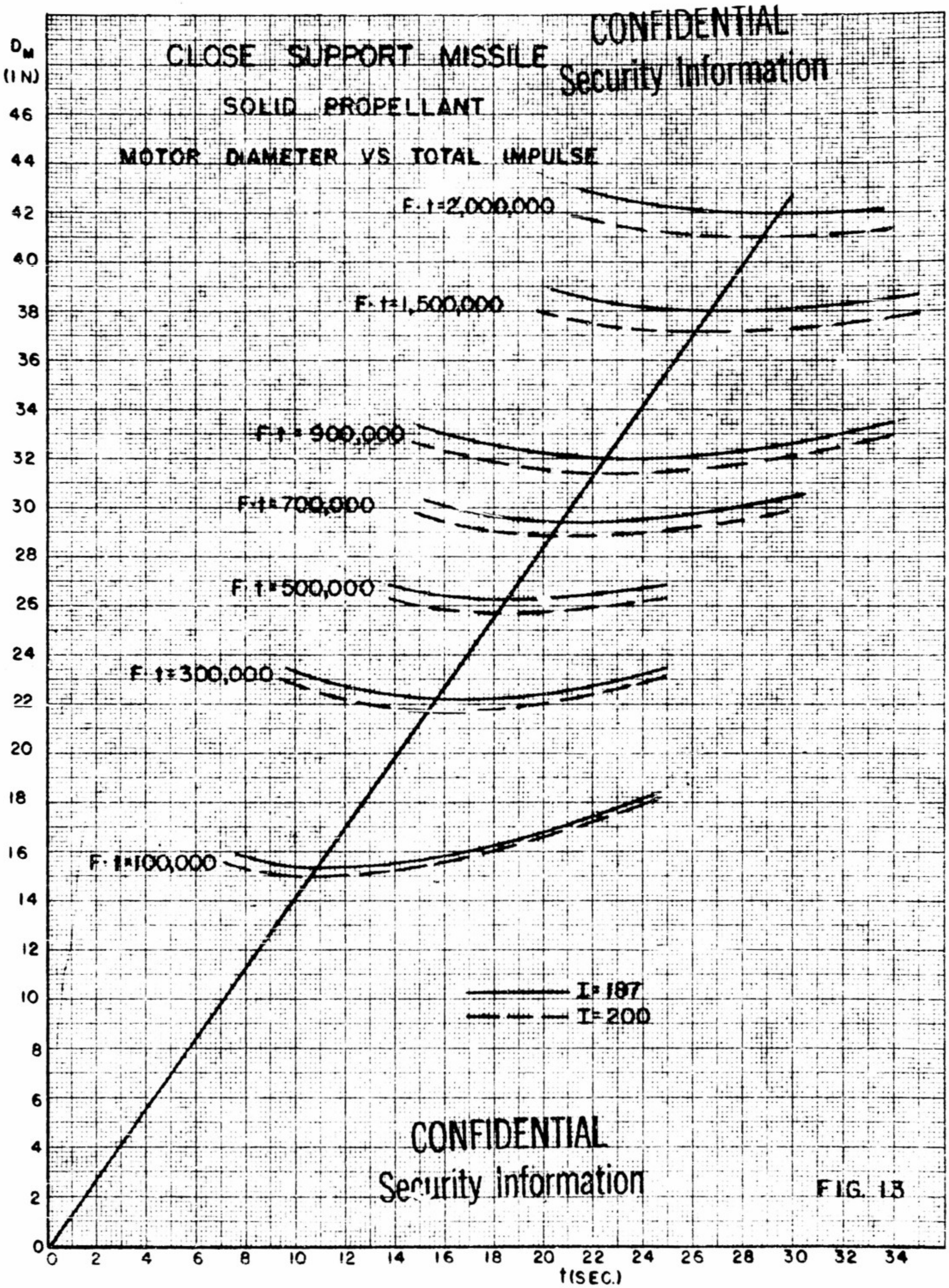
FIG. 11



SECTION (ENLARGED)

SCHEMATIC OF 5 POINTED STAR CONFIGURATION

FIG. 12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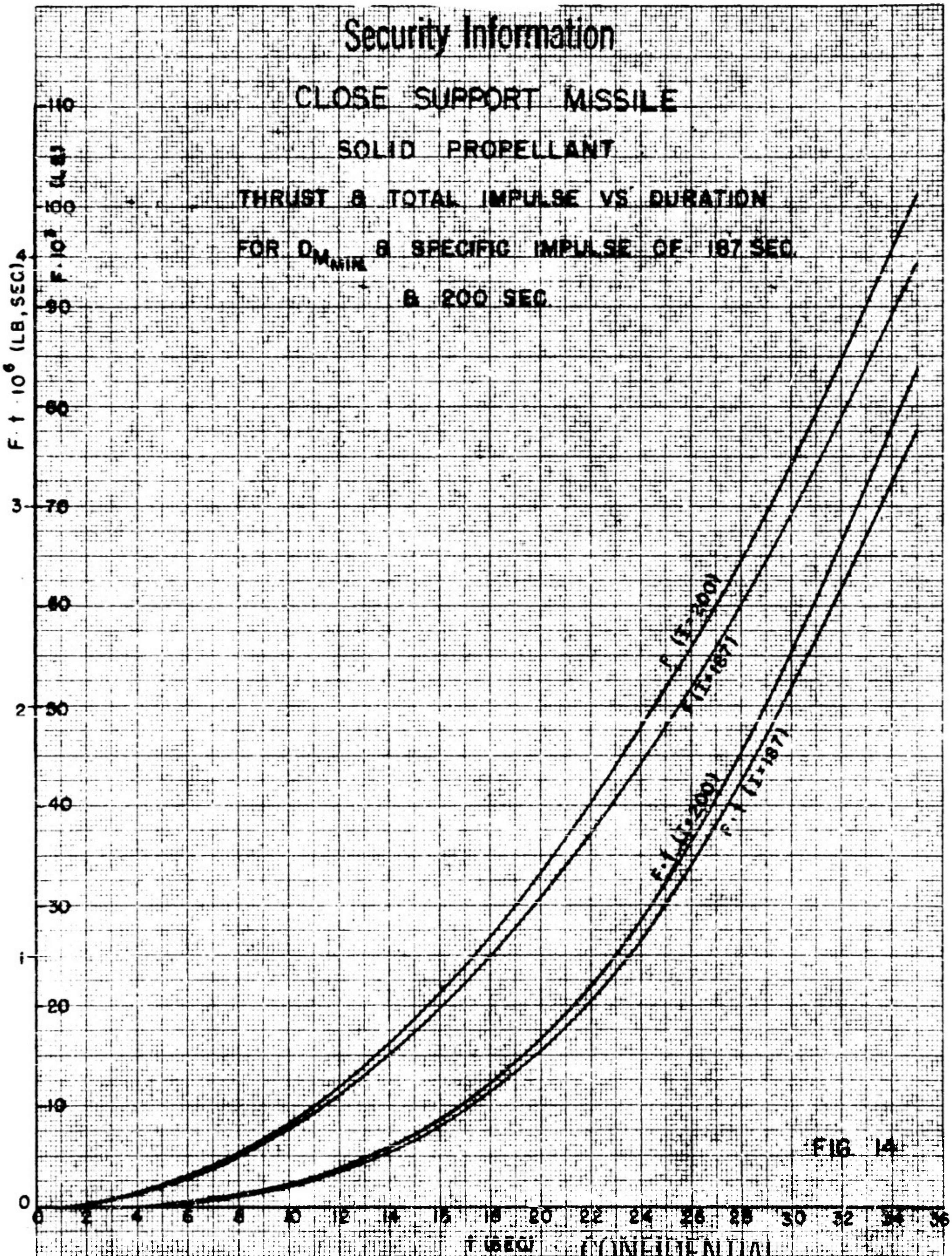
CLOSE SUPPORT MISSILE
SOLID PROPELLANT
MOTOR DIAMETER VS TOTAL IMPULSE
D_M (IN)
F·t=2,000,000
F·t=1,500,000
F·t=900,000
F·t=700,000
F·t=500,000
F·t=300,000
F·t=100,000
I=187
I=200
t(SEC.)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46

FIG. 13



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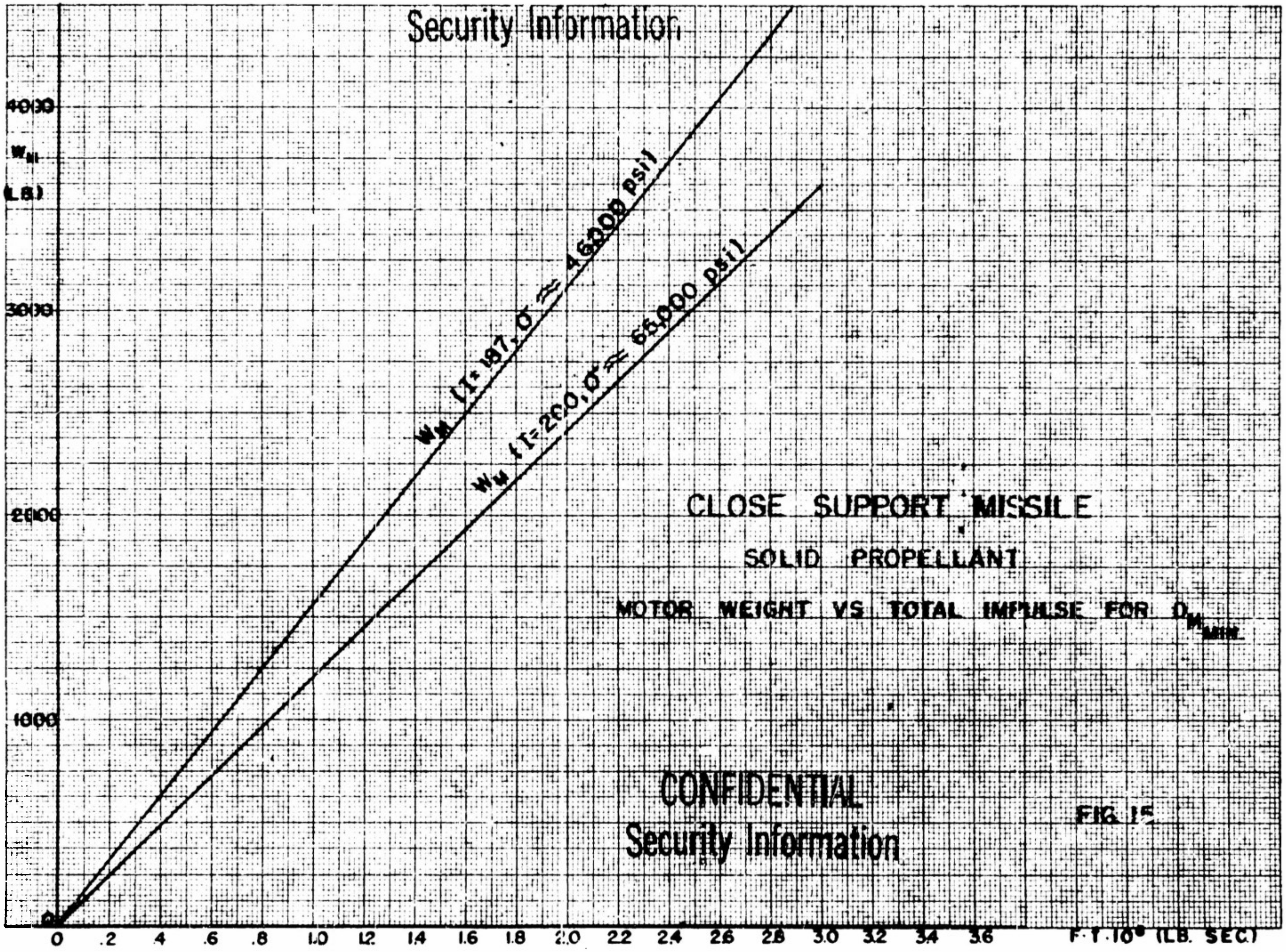

FIG. 15

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